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The Navy's Probability of Raid Annihilation Assessment Process Standards & Architecture and Systems Engineering Concept Model

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ABSTRACT: *The U.S. Navy has established a Probability of Raid Annihilation (P_{RA}) Assessment Process to be used for each new ship class. Papers presented at previous SIW meetings have described the P_{RA} and the development of certain aspects of the P_{RA} Assessment Process, including the P_{RA} Federation Testbed. This paper provides an overview of the total P_{RA} Assessment Process to illustrate how the process provides the P_{RA} ship class results to meet OPEVAL requirements across ship classes in a consistent and adequate manner.*

The P_{RA} Assessment Process as applied to each new ship class will build on the products and results, including the P_{RA} Federation Testbed as implemented, from previous ship class work. To facilitate this reuse, all relevant material, collectively referred to as the P_{RA} Assessment Process Standards and Architecture (PS&A), is documented in one module. The PS&A module is the roadmap for any new ship class's program manager and technical team to implement the P_{RA} Assessment Process, including documentation and products.

The PS&A shows how the steps in the P_{RA} Assessment Process correlate to the steps in the FEderation Development & Execution Process (FEDEP) model: requirements, conceptual modeling, design, software development, integration, and execution. VV&A is not a separate step but overlays all of the steps in the FEDEP and in the P_{RA} Assessment Process. The PS&A includes the documents and products associated with each FEDEP step, including the Systems Engineering Concept Model (SECM). The discussion with the SECM captures both the real world and simulated views. In addition the SECM starts with a generic conceptual view and then granulates to specific applications. This approach takes advantage of what is common among the ship classes while capturing the critical differences as they relate to the ability of a single ship to defend itself against a threat raid.

1. Introduction

The Probability of Raid Annihilation (P_{RA}) Measure of Effectiveness (MOE) is the measure of a single ship to

defend itself against multiple anti-ship cruise missile threats (a raid). The Navy has determined that the P_{RA} MOE must be assessed for each new ship class. As part of a risk mitigation strategy, the P_{RA} Assessment Process

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Standards & Architecture (PS&A) has been developed to meet OPEVAL requirements in a consistent and adequate manner. The PS&A is designed to reduce costs by using standard practices and tools and by building on previous ship class work. The PS&A provides an approved roadmap for each ship class's program manager and technical team to assess the P_{RA} MOE for that ship class.

The P_{RA} MOE is difficult to assess with traditional testing that is done both at sea and in laboratories. Although cost is a limiting factor, a more important consideration is the inability to provide complete scenarios that include all relevant military systems, ship and threat, to test their behaviors and interactions during the "detect, control and engage" timeline for ship self defense. Therefore the Navy has developed the P_{RA} Assessment Process to include interoperable simulations together with a robust validation process that incorporates all available results from sea-based and land-based testing trials. Further details on P_{RA} can be found in earlier papers. [7], [10]

The P_{RA} Assessment PS&A is based on the Program Executive Office (PEO) Integrated Warfare Systems (IWS) Systems Engineering Process, which does address Modeling & Simulation. The PEO IWS Systems Engineering Process [9] has been developed using standard systems engineering techniques and tools. The High Level Architecture (HLA) FEderation Development and Execution Process (FEDEP) incorporate system engineering methods tailored to federation development. [5] This paper will describe the P_{RA} Assessment PS&A and its relationship to the FEDEP, including the relation of the Systems Engineering Concept Model (SECM) to the Federation Concept Model. Then the SECM steps as applied to the P_{RA} Assessment PS&A are described in detail.

2. Systems Engineering

Systems engineering as a specialty has been established to guide the engineering of a complex system or family of systems. The process is not restricted to just hardware or manufacturing but in fact covers any program or project from its inception to product implementation to retirement of such products by outlining in general terms the required steps and documentation required. Systems engineering can be considered to be a common sense approach to development. It is the responsibility of the systems engineer to employ practices that are of sound judgment from cost, schedule, performance and risk objectives including the needs and requirements of the customers. Systems engineering documentation is high level and refers the reader to accepted standards, guidelines and IEEE publications. These standards have been developed to be rigorous in nature for continued repeatability and consistency among systems.

2.1 The Program Executive Office (PEO) Integrated Warfare Systems (IWS) Systems Engineering Process

The Program Executive Office (PEO) Integrated Warfare Systems (IWS) Systems Engineering Process [9] addresses the performance baseline, functional baseline, allocated baseline and product baseline for a system or in some cases a family of systems. The documentation is high level and refers the reader to DoD standards, guidelines and IEEE publications. The PEO IWS Systems Engineering Process can be shown graphically (Figure 1) and includes a detailed checklist. The purpose of the checklist is to provide the program manager a useful tool to ensure that the key systems engineering questions have been answered as early in the program as possible. By doing this, the systems engineer is able to use the attributes of the systems engineering process to the greatest advantage, thus achieving total system optimization as opposed to applying bigger corrections farther along the development process. The checklist also serves as a reminder/aid for the program manager and the program systems engineer in meeting the technical systems engineering and performance requirements of the program.

The PEO IWS Systems Engineering Process includes the option of using Modeling & Simulation in its broader meaning of computer-aided tools and techniques, but M&S is an aspect of the overall systems engineering process.

2.2 The High Level Architecture (HLA) Federation Development and Execution Process (FEDEP)

The High Level Architecture (HLA) is a general purpose architecture that supports interoperability and reuse across the many different types of simulations developed and maintained by the DoD. The HLA Federation Development and Execution Process (FEDEP) describes a generalized process for building HLA federations. Both the HLA and the FEDEP have been developed under the leadership of the Defense Modeling and Simulation Office (DMSO). [5] The FEDEP does not replace any existing management or engineering processes; rather it provides a high-level framework for HLA federation construction into which lower-level development practices native to each individual application area can be easily integrated. The FEDEP defines a generic, common sense systems engineering methodology for the HLA that can and should be tailored to meet the needs of individual applications. The systems engineering formality is determined by the size and complexity of the applications being used. The FEDEP also includes checklists associated with the various stages of federation development, from definition of federation objectives to federation integration and execution. The checklists track particular docu-

ments, products, and decisions expected to result from passage through a given process step. These checklists are similar in nature to the checklists used for the PEO IWS Systems Engineering Process.

The HLA FEDEP in conjunction with its checklist are offered to the community as a framework for identifying and addressing general issues as discussed within the full

context of end-to end process model for the development of distributed simulation environments that fully conform with the HLA specifications. The FEDEP is instantiated as a six-step process that can be implemented in many different ways depending on the application. Thus it follows that the time and effort required to build an HLA federation may also vary significantly.

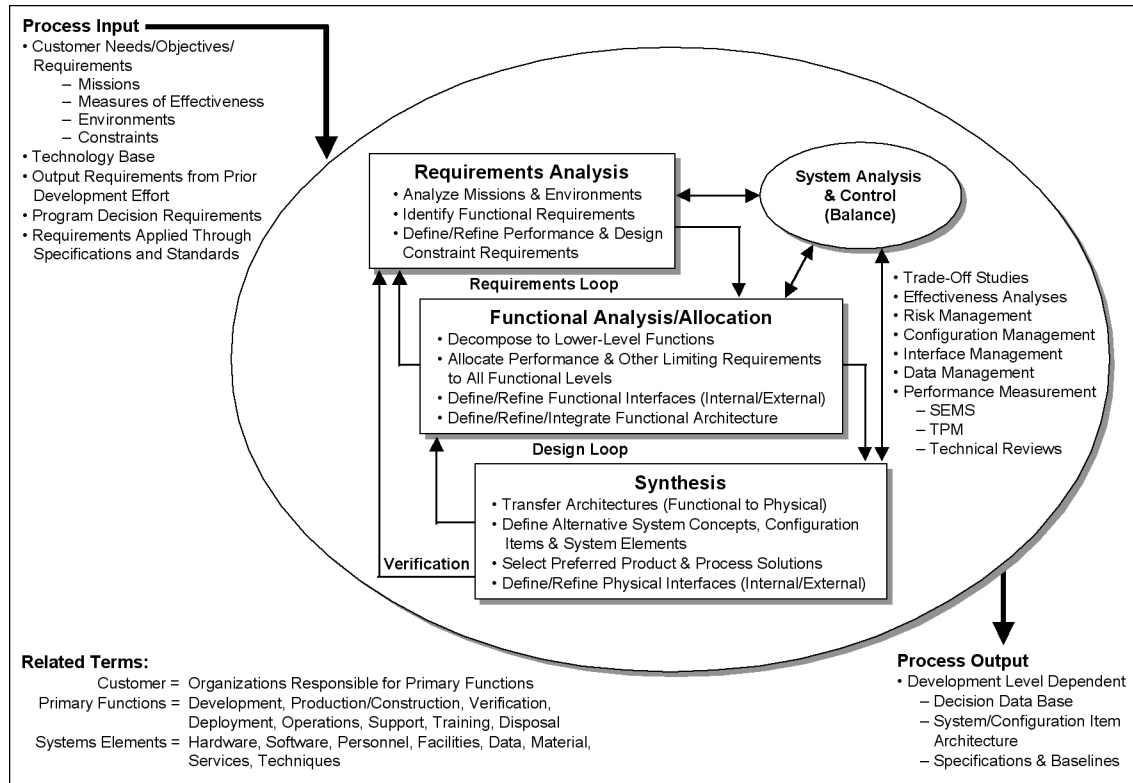


Figure 1. The PEO IWS Systems Engineering Process

2.3 P_{RA} Assessment PS&A Compared to HLA FEDEP

The P_{RA} Assessment PS&A, based on Figure 1, can be described generally in six steps similar to those of the FEDEP. [5] The comparison is as follows:

FEDEP Step 1: Define federation objectives.

The federation user and federation development team define and agree on a set of objectives and document what must be accomplished to achieve those objectives.

PS&A Step 1: Process Input.

The customer needs, objectives and requirements are determined. A technology base is determined, program decision requirements are made and requirements are applied through specifications and standards.

FEDEP Step 2: Develop federation conceptual model (FCM).

Based on the characteristics of the problem space, an appropriate representation of the real world domain is developed along with federation requirements and test evaluation criteria.

PS&A Step 2: Requirements analysis/SECM

Analyze missions and environments, identify functional requirements, define/refine performance and design constraint requirements.

FEDEP Step 3: Design federation.

Federation participants (federates) are determined, required functionalities are allocated to the federates and the federation development plan is designed.

PS&A Step 3: Functional analysis/allocation.

Decomposition to lower level functions is completed. The allocation of performance and other limiting requirements to all functional levels is done. Functional interfaces both

internal and external are defined or refined as needed, as well as the functional architecture.

FEDEP Step 4: Develop federation.

The Federation Object Model (FOM) and FED files are developed, federate agreements on consistent databases/algorithms are established, and modifications to federates are implemented (as required).

PS&A Step 4: Synthesis.

Transfer of architectures from functional to physical. Alternative system concepts are defined along with configuration items and system elements.

FEDEP Step 5: Integrate and test federation.

All necessary federation implementation activities are performed, and testing is conducted to ensure that interoperability requirements are being met.

PS&A Step 5: System analysis & control (balance).

Trade-off studies are completed, effectiveness analyses and risk management are determined. Configuration management and interface management and data management are performed. Performance measurements including the Technical Performance Measures (TPM) and Technical Reviews are executed.

FEDEP Step 6: Execute federation/prepare results.

The federation is executed, outputs are generated and results are provided.

PS&A Step 6: Process Output.

The process output is development level dependent. A decision data base is developed, system configuration item architectures are established and specifications and baselines are established.

The primary difference between the PS&A and the FEDEP is that the PS&A includes a federation as one of the tools used in the entire program while the FEDEP is specific to federations. A second difference is that the PS&A uses the conceptual modeling in a very broad sense. Although the SECM is shown in the PS&A step 2, it is used throughout the entire P_{RA} Assessment Process to capture, link and display as much of the information as possible for analysis and ready access.

All information, documents and products relating to the P_{RA} Assessment PS&A are included in a CD_ROM for ready access and review. The products include the SECM, the P_{RA} FOM and FED files, and the P_{RA} Federation Agreements.

3. Systems Engineering Concept Model (SECM)

The SECM methodology is general and can be applied to many different types of programs, not just to those involving interoperable simulations. The methodology includes both the process and a product. The process is general and can be applied to any program but the product is specific to a given program although many parts of a SECM product may be reused in related programs. The SECM, as the name implies, involves conceptual modeling. In general, a concept model views the world, real or simulated, as consisting of objects with defined properties and behaviors that interact in prescribed ways. [1] The SECM makes extensive use of graphical representations that use a precise set of rules or language in capturing information for display. [6] The SECM also captures the detailed analysis performed to develop the federation requirements; therefore it can serve also as the basis for the Verification & Validation process required for all simulations. [8], [12]

The SECM methodology has three critical factors which must be considered at all stages of development. First, a careful identification must be made of what is relevant and what is not relevant to the program objectives. What is relevant will shift because the program objectives will be modified due to changes in resources, priorities, and stakeholders. Second, for programs involving models and simulations, a clear separation must be made between the real world view and the simulated world view. The SECM product or electronic document provides traceability for all decisions, constraints, approximations and assumptions leading from the real world view to the simulated world view as well as capturing the complete details of each view. Third, the objects in the military systems interact through and with the natural environment, whether in the real world view or the simulated world view. Therefore, the natural environment system itself should be treated as consisting of objects with defined properties and behaviors that interact in prescribed ways.

The main steps in developing the SECM for the P_{RA} Assessment Program are as follows:

1. Develop Use Cases
2. Identify Systems Generic (real world view only)
3. Identify Systems Specific
4. Capture System Interactions (may be done before Step 3 as well)
5. Develop Scenario Environment

These series of steps are done twice: first for the real world view and second for the simulated world view based on what has been captured for the real world view. The question arises as to how the data from the testing trials, both sea-based and land-based, fit in. To date, the data is captured as part of the real world view to be used

in the VV&A process for the P_{RA} Federation. However, for future work, the testing trials information may be used to develop scenarios for the P_{RA} Federation runs to facilitate the comparison between the test results and the P_{RA} Federation results. [11]

The importance of the natural environment to simulations and the use of concept models to develop that natural environment have been presented in previous papers. [3], [4]

3.1 The Real World View

The <Real World System> can be divided into three classes: <Humans>, <Natural Environment System> and <Human-Made Systems>. Some stakeholders have classified certain human-made structures, such as non-military and fixed structures, as part of the natural environment. The developers of the SECM procedure have found that keeping all human-made structures in the <Human-Made Systems> is more straight-forward to most stakeholders. The essential point is that all stakeholders must agree on which classification is used. (Figure 2.)

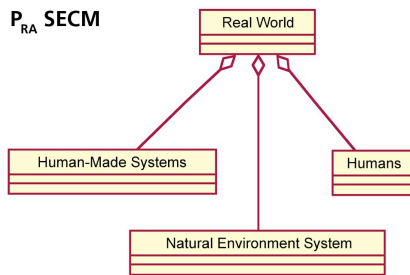


Figure 2. The Real World System/View

The two classes <Humans> and <Human-Made Systems> can be further divided into Civil and Military classes. Another possible division is into Friend and Foe, depending on the scenarios being developed.

3.1.1 Develop Use Cases – Real World

Strictly speaking, a Use Case represents one completed set of actions between a user and a software system. However, the term has evolved into more general usage including that of scenario.

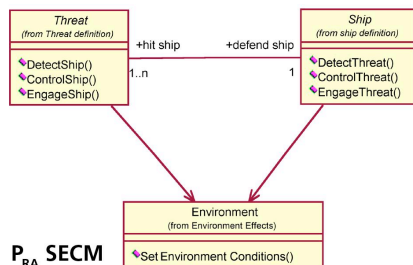


Figure 3. Scenario – Top Level View

The first step in detailing the Scenario Use Cases is to identify the objects involved in the P_{RA} scenarios. As seen in Figure 3, the smallest number of objects or classes involved in the scenario is three: the ship, the threat and the natural environment. <Humans> are not included. The number of threats has not been specified at this point but there can be one or more than one. The number of ships is limited to one for current scenarios. The top level view shown in Figure 3 captures these classes and some details of their relationships. The threat and the ship are associated. The role of the threat is to hit the ship and the role of the ship is to defend the ship. The numeral 1 to the left of the ship class indicates that one ship is involved. The numerals 1...n to the right of the threat class indicates that the number of threats can be 1 to n where n is agreed upon by the stakeholders. The notation within the class boxes show where the classes are defined in detail. Both of these classes are associated with the environment class. Again, the notation is precise. Only one environment is involved. Further, the direction of the open arrows indicates responsibility. The threat class has the responsibility to tell what environment it uses or needs. Similarly, the ship class has the responsibility to tell what environment it uses or needs. And the environment class as a whole must be common. Only after the environment class in detail is determined can the environment class in turn tell what the environment database should be. These concepts of classes and relationships are not merely graphical but are inherent in the rigor applied to the way in which the information is captured in the electronic document.

The object classes and some interactions for the P_{RA} scenario are shown in Figure 3 but the Scenario Use Cases capture the events in the scenario. There are several ways to view the Scenario Use Cases. One which focuses on the activities in the P_{RA} scenario is shown in Figure 4. The ship behavior includes (detect, control and engage) the threat while the threat behavior includes (detect, control and engage) the ship. However, the ship behavior itself and the activities of detecting, controlling and engaging the threat all use the environment effects. And the same is true for the threat behavior and activities. The arrow style used here shows that the behaviors and activities all have the responsibility to indicate what environmental effects they use.

The SECM process uses as many views as necessary to clarify what is happening. Not all views can show all classes and interactions. However, once links between objects are established, those links will remain whenever those two objects are used again. For example, any view that has both <Ship> and <Threat> included will also include the link shown in Figure 3.

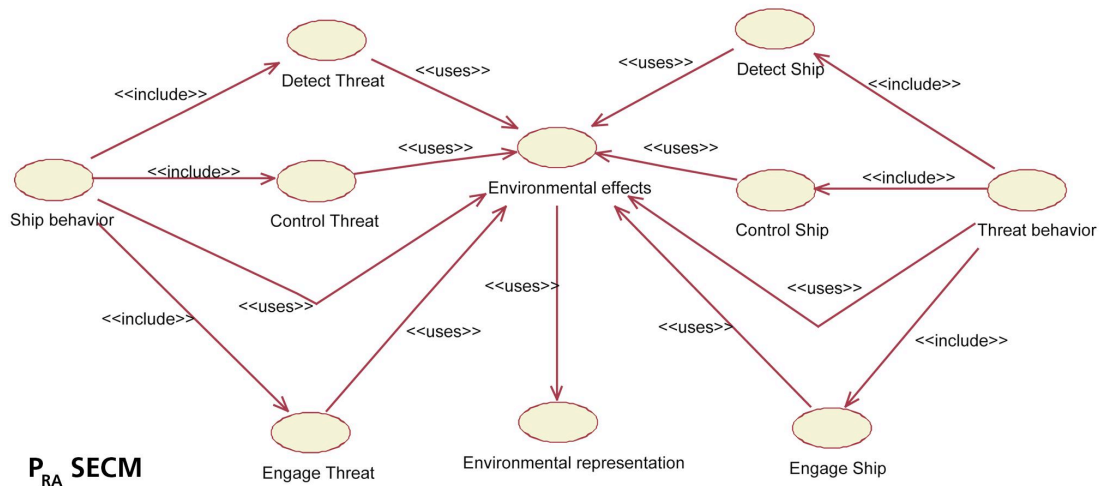


Figure 4. Use Case with Behaviors Identified – Real World View

3.1.2 Identify Military Systems – General – Real World View

Once the Scenario Use Cases have been defined for the P_{RA} scenario, the details needed for the various military systems are needed. For example, a ship consists of various parts or components. These components aggregate into the whole that is called the ship. For the P_{RA} scenario the chief classes of ship components are the sensors,

weapons, and the ship platform itself. Obviously, these are not the only components of a ship. However, they are the minimum relevant set for this P_{RA} scenario as agreed by all stakeholders. At this point, some flexibility is possible. Each of the three ship components (classes) can be broken down into further components if desired. For conciseness, only the breakdown for the sensors will be shown.

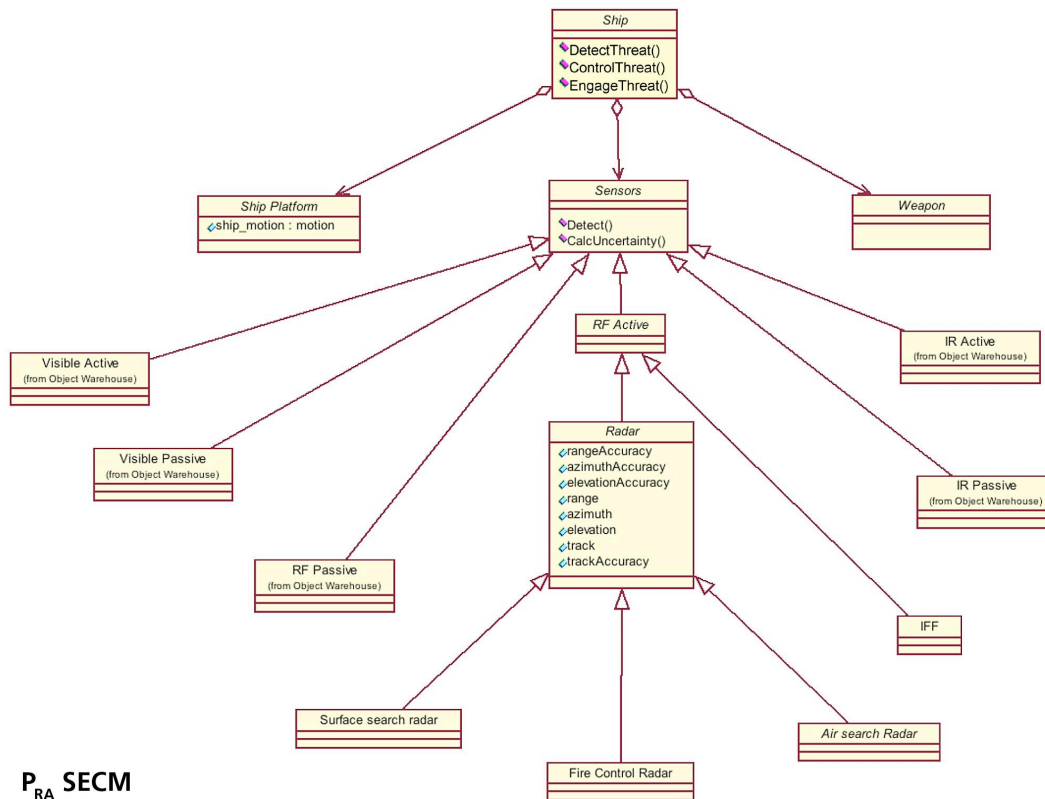


Figure 5. Ship Definition: Sensors (Partial View) – Real World View

Sensors in general are categorized as either active or passive. Furthermore, sensors are categorized by the particular EM frequencies that they sense. Thus, it is logical to define classes for both the active and passive sensors in the most common EM ranges: RF, IR and Visible. All of these classes aggregate into the class labeled Sensor in Figure 5. Again, to avoid complicating the view, only the RF Active class is further divided. The classes of RF Active Sensors included here are: Radar and IFF (Identification Friend or Foe). RF Active Radars have several different functions aboard a ship, including fire control, active search and surface search. Some Attributes of the Radar Class are shown in that box in Figure 5. An RF Active Radar will provide target range, azimuth, elevation and track, each with a particular accuracy, depending on the specific type of radar. The accuracies are detailed as At-

tributes because the P_{RA} MOE will itself have an uncertainty that will depend on the accuracy of every element involved in the P_{RA} Scenario.

3.1.3 Capture System Interactions

The sensors, weapons, and the ship platform interact in various ways. These interactions must also be captured. For example, the ship's weapons can include decoys which alter or mask the ship platform signature. The part (frequency range) of the signature that is altered depends on the type of decoy. This type of interaction is shown in Figure 6. It illustrates that the entities on the ship, decoy and platform, have a relationship that involves the natural environment.

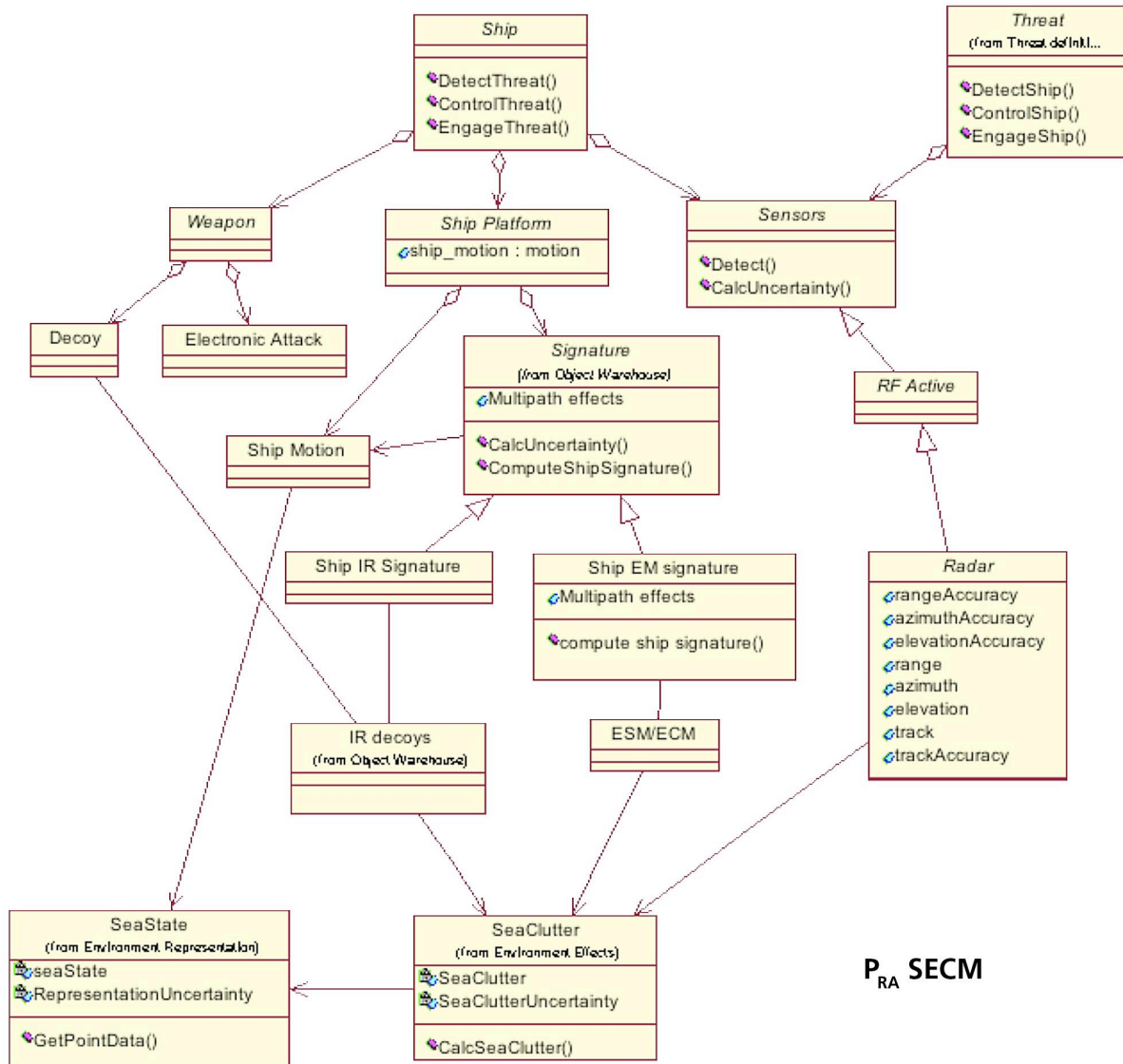


Figure 6. Ship Definition: Platform (Partial View) – Real World View

The discussion to this point has been intended to provide an understanding of how the SECM process has been used to develop the P_{RA} SECM. The P_{RA} SECM itself has many more views and details of the Use Cases and the military systems than have been shown here. Furthermore, the concept model development to this point has been very general. Ship class has not been specified nor have the specific weapons or sensors. This approach is intentional to permit the P_{RA} SECM to be reused for a wide range of ships, weapons and sensors. Furthermore, Figure 5 does not show all of the environmental effects that will be used by the various classes depicted. Capturing all of the relevant environmental effects and illustrating them at this general level is very complex. A Standard

Environment Template for each Military System Class is under development to simplify both the capture and display at this general level.

3.1.4 Identify Military Systems – Specific – Real World View

The next step in the P_{RA} SECM development is to specify the military systems being considered in a particular P_{RA} scenario. One scenario may have three specific sensors for the ship: SLQ-32, SPQ-9B, and SPS-49 with the RAM Block 0/1 being the weapon for the hard kill. The ship may be the LPD-17. These are shown in Figure 7.

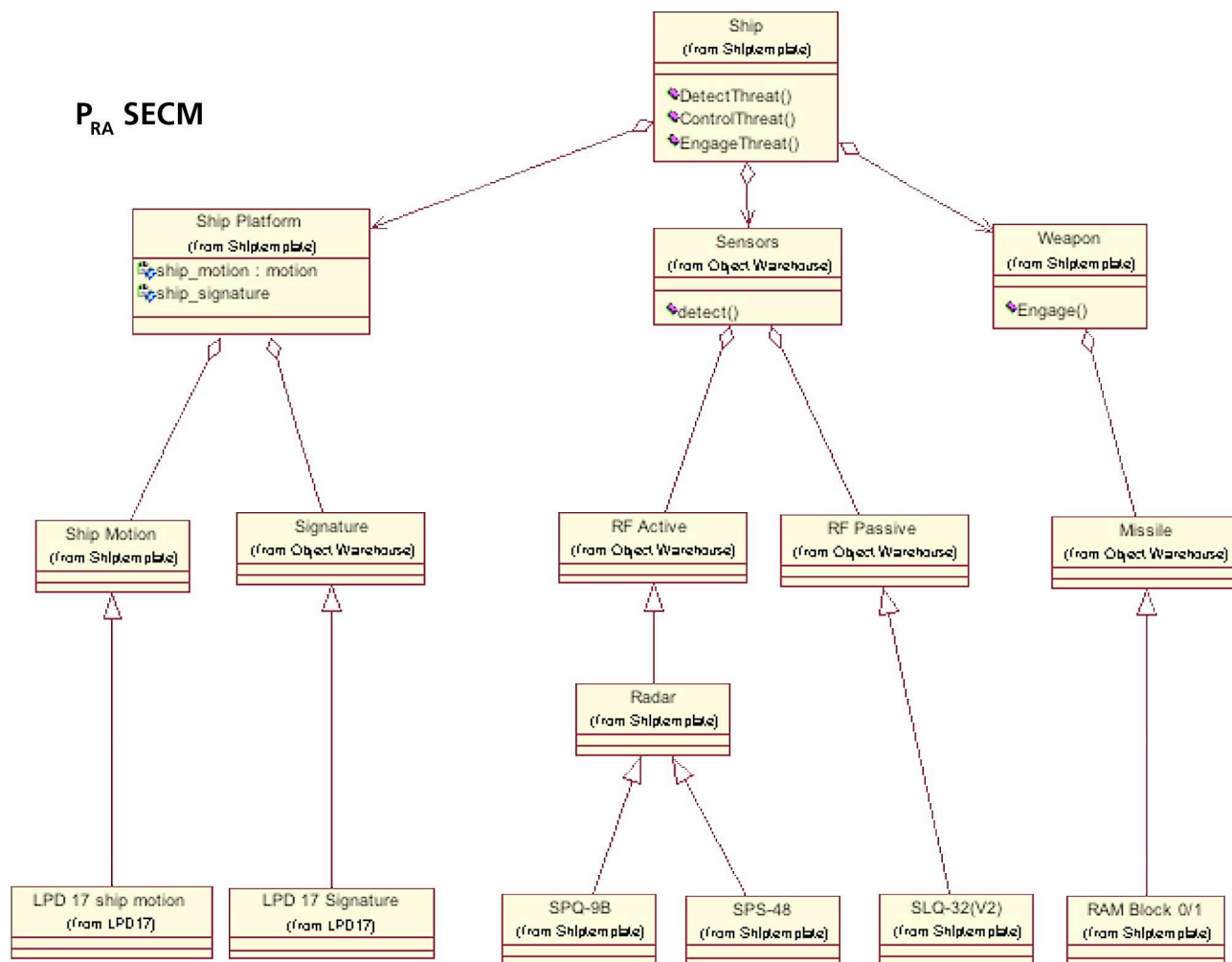


Figure 7. Ship Definition: Military Systems – Specific

Once the specific ship systems are identified, all interactions among the ship systems must be identified, including what type of information is passed among the systems. Further, the natural environment parameters that affect the behavior, performance and interactions for each ship system must be captured as well. The Standard Envi-

ronment Templates are a useful starting point but must be examined for each specific military system. Each new system generally has differences behavior, performance and interactions, especially with the natural environment than the existing systems of that class.

3.1.5 Develop Scenario Environment

The analysis done for the ship has to be done for the threat as well. Further, the interactions between the ship and threat have to be captured as well as between the threat and the natural environment. Once all parameters of the natural environment have been captured for each specific military system and for all interactions, the information can be combined and analyzed for the total inferred natural environment. The term ‘inferred’ is used because the parameters must be inferred from the behavior and interactions of the military systems in the real world scenario. The parameters cannot be determined before the complete analysis is done. See Figure 8.

Two classes included in Figure 8 generally are not considered to be natural environment effects: location and orientation. The P_{RA} developers have determined that the location and orientation for each and every military system play a vital role in assessing the P_{RA} MOE. Further, the natural environment data values that affect each military system will be functions of location and, sometimes, orientation as well. Therefore, to ensure location and orientation information is captured and linked for all military systems, these classes are included as part of the inferred natural environment system.

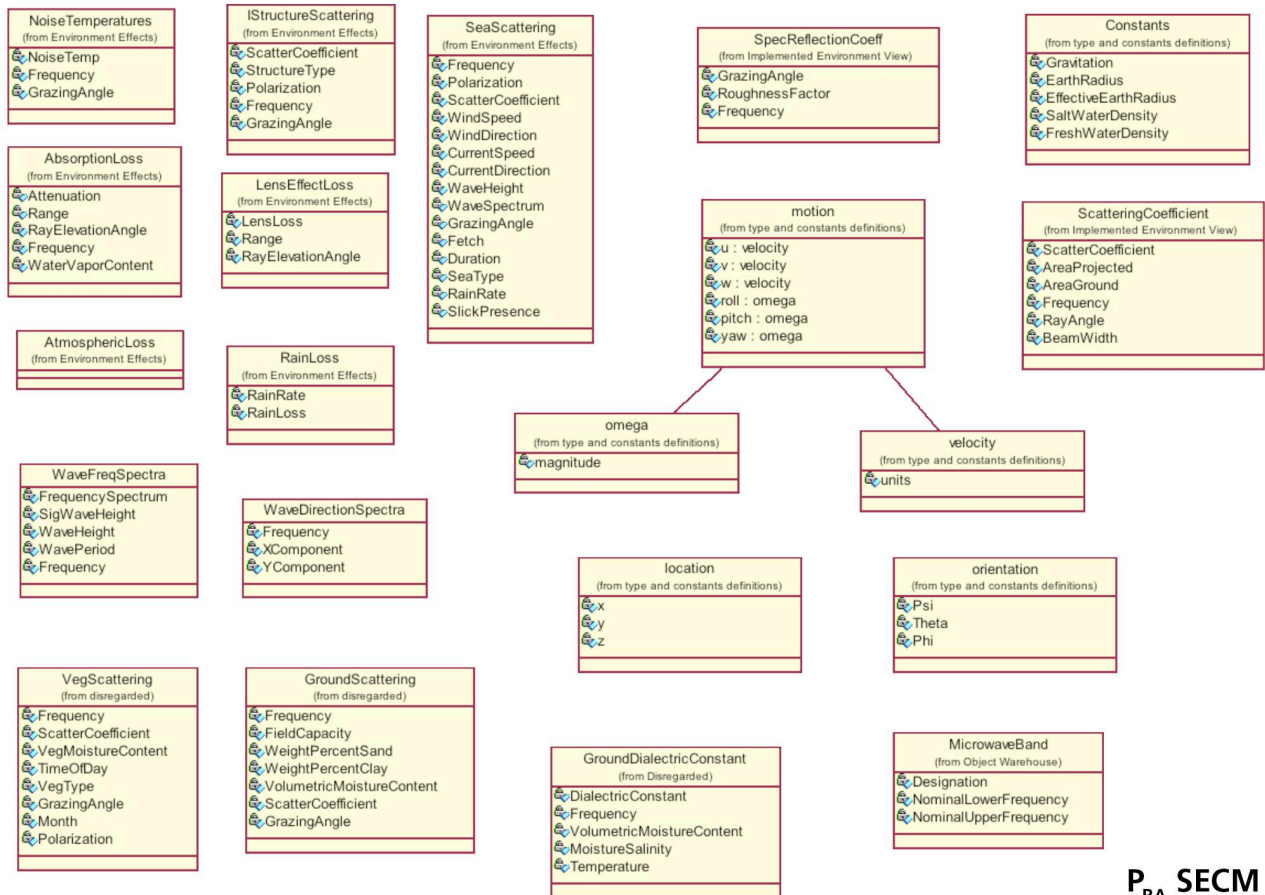


Figure 8. Inferred (Real World View) Natural Environment for the P_{RA} Assessment Process

3.2 Simulated World View

3.2.1 Develop Use Cases – Simulated World View

At this point, the analysis turns finally to the simulated world view, or what is in the actual P_{RA} Federation. The first step is to develop the Use Cases. Here, the term Use Cases refers to the specific events that comprise one pass through the P_{RA} Federation, not what happens in the real world view. The Use Case to Assess the P_{RA} MOE with

the P_{RA} Federation is shown in Figure 9. This Use Case Diagram does not contain all details but it is indicative of the differences between the Use Cases for the real world view and those for the simulated world view.

As noted in Section 3, the Step 2 “Identify Systems Generic” is omitted for the simulated world view. The reason is that in the simulated world view, the classes captured represent models of the real world systems, not the systems themselves, and generic models are rarely available

and not relevant to the P_{RA} program. Thus, the next step is to identify the military systems specific. This view, not shown here, appears to be identical to that shown in Figure 7 except for a label of Simulated World in place of Real World. However, the classes shown are models of the specific military systems, not the military systems themselves. Therefore the SECM process must capture the attributes and behaviors of the models themselves. The model attributes and behaviors will be primarily a subset of those of the real world military system. However, the models may have additional attributes and behaviors not found in the real world system. For example, some models contain natural environment parameters and databases. Two models may use the same natural environment parameters internally but have different values for these parameters.

3.2.2 Capture System Interactions – Simulated View

The system interactions for the simulated view depend not only on model attributes and behaviors but how these models are linked into the P_{RA} Federation. A simplified view of the P_{RA} Federation is shown in Figure 10. The interactions for this P_{RA} Federation are determined by tracking information into and out of each model and each federate. The interactions occur **across the HLA RTI** but also **within each federate**. Many of these models and federates are legacy systems and may contain algorithms and databases that are inconsistent with those found in other models and federates. All of this information must be captured and analyzed in order to evaluate the merit of the P_{RA} MOE that is obtained from the P_{RA} Federation runs.

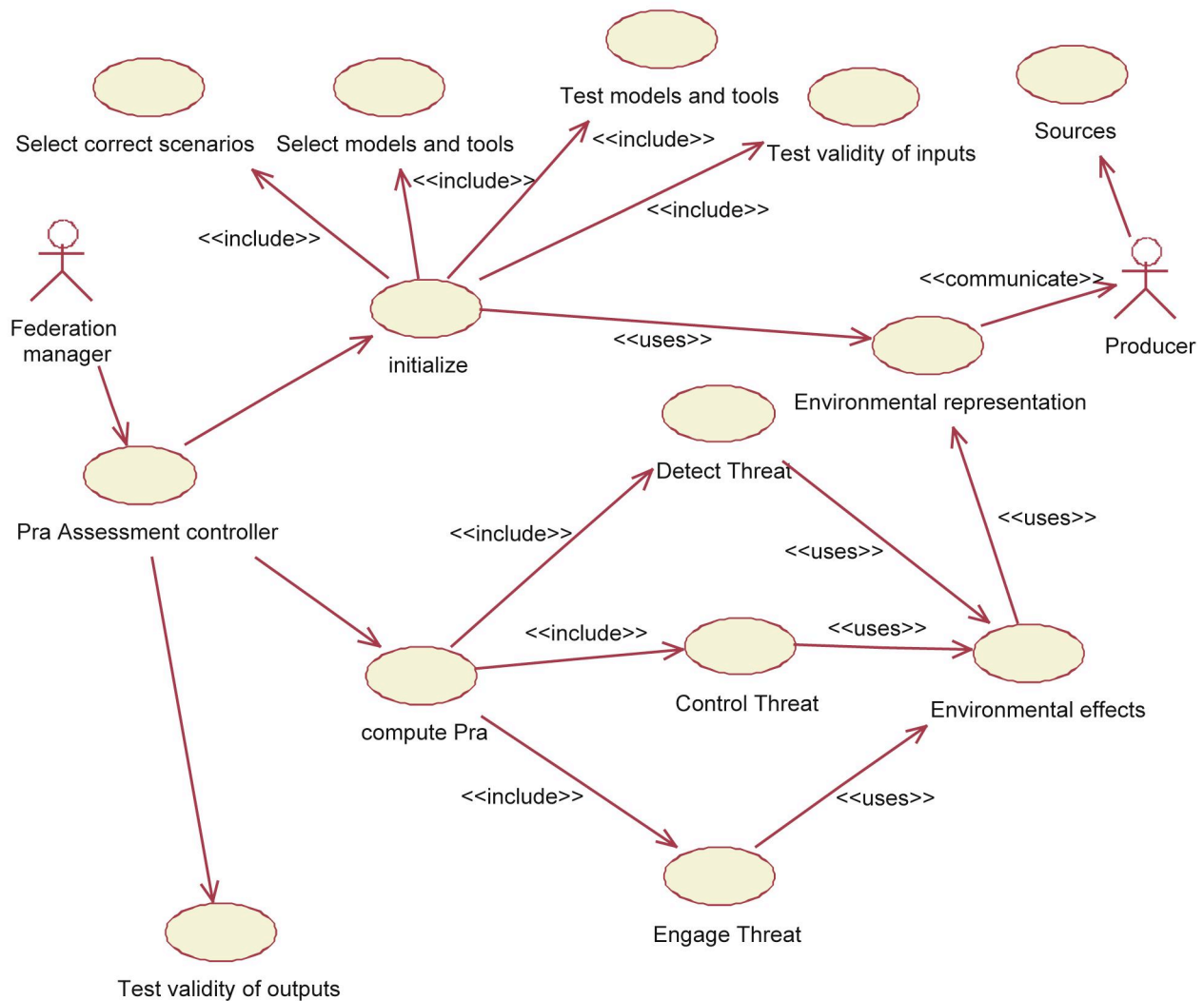


Figure 9. Use Case – Simulated World View

To demonstrate how different algorithms can cause problems, consider location and orientation. Many of

the military system models use a body-centric coordinate system. The origin of that coordinate system must

be identified as well as the type of coordinate system. Most body-centric coordinate systems are Cartesian (X, Y, Z) but the Z axis may be “up” relative to the body or “down”. As information is passed into and out of a

model or federate, coordinate system transformations have to be made, even if the stakeholders agree that there is only one coordinate system to be used for information passed across the RTI.

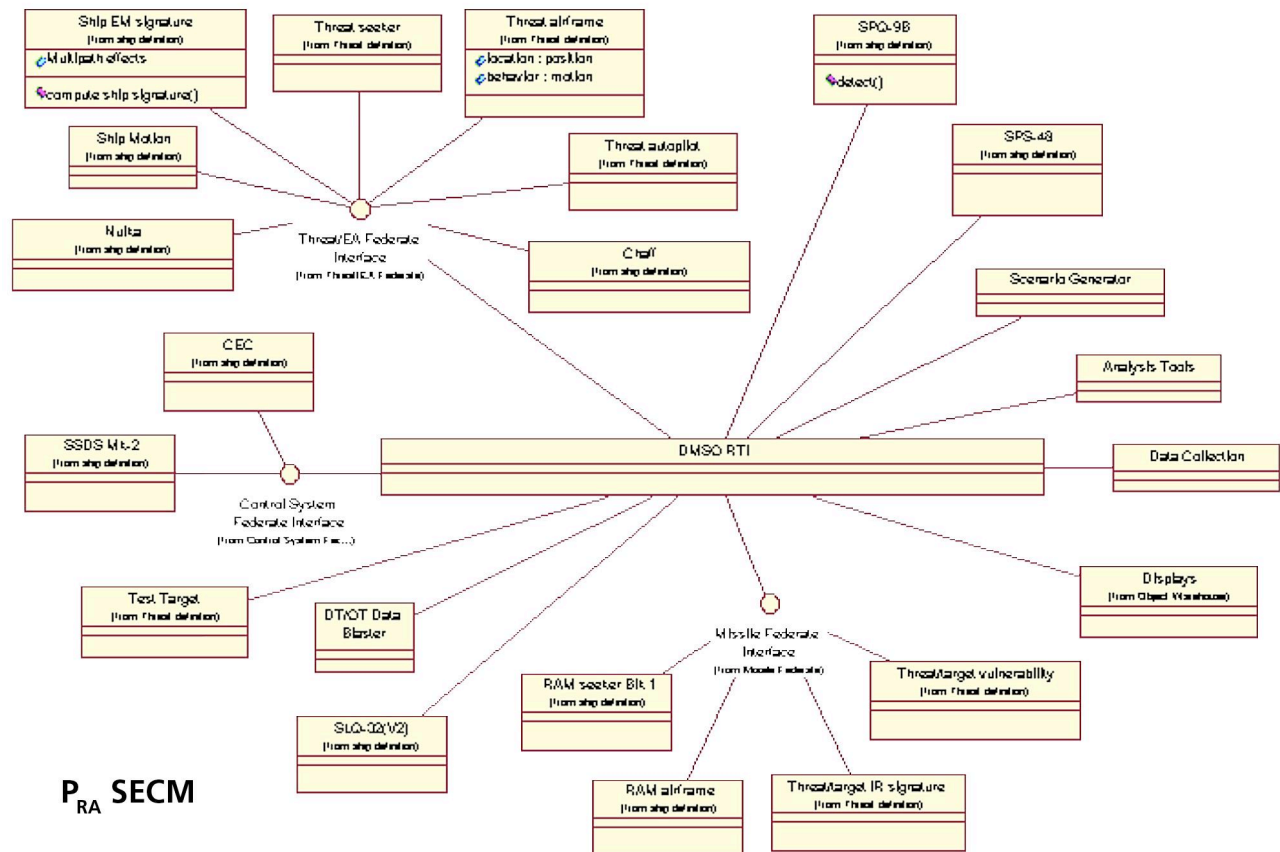


Figure 10. The P_{RA} Federation – Simulated World View

3.2.3 Develop Scenario Environment – Simulated World View

The SECM captures what natural environment information moves into and out of each model and federate and how that information is added to or modified and applied within each model and federate. Then all of these captured aspects of the natural environment are analyzed to identify what the common and consistent natural environment should be for the P_{RA} Federation as a whole. The resulting list of parameters should be a subset of what is in the inferred natural environment. (Figure 8) Otherwise, there is an inconsistency between the real world and the simulated world that will impair the validity of the federation results. The implemented natural environment includes not only the identified parameters, but the appropriate spatial and temporal resolution for each parameter. The scenario/environment generator (Figure 10) supplies the implemented natural environment data for each P_{RA} federation run. Each model and federate must be set to

receive and implement the natural environment data supplied by the scenario generator to insure a “level playing field”.

4. Reuse

The P_{RA} Federation will be modified for each ship class as the specific ship military systems are changed in the real world view. The P_{RA} Federation will be modified as the Federation itself is changed. Further the threat shown above has not been specified. A single ship class may be tested against several types of threats in determining the P_{RA} MOE. Each of these changes must be captured in the SECM. However, large portions of the SECM can be reused. For example, once the SPQ-9B model has been analyzed, that analysis can be reused until the SPQ-9B model is modified. And an additional sensor or weapons can be added to the existing ones in the real world and then linking that sensor or weapon model to the existing federation. The entire simulated world view does not have

to be created from the beginning. Only the attributes, behaviors and interaction of the new sensor or weapon model needs to be incorporated. The sharing and reuse of concept models, especially in relation to developing the natural environment requirements, has been addressed in a previous paper [2]

5. Summary

The P_{RA} MOE is a measure of ship defense capability and must be assessed for each new ship class. The P_{RA} Assessment PS&A provides a roadmap for the assessment process, including the development of a federation testbed to be used for various scenarios. Both the PS&A, which follows the PEO IWS Systems Engineering Process [9] and the FEDEP [5] are based on common systems engineering practices, including the use of conceptual modeling.

The Systems Engineering Conceptual Model (SECM) is used to develop requirements and to capture all assumptions, approximations, and limitations leading from the real world view to the simulated world view. This information, together with all relevant documentation and discussion captured in the SECM, support the VV&A process. The results from testing trials, both at-sea and land-based, are also used in the VV&A process.

The PS&A, including the SECM, are designed for reuse and extension. This standardization and reuse promotes risk mitigation and cost reduction for the Navy's P_{RA} Assessment of the MOE for each ship class.

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